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Design of a Programmable Four-Preset Guitar Pedal

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Design of a Programmable Four-Preset Guitar Pedal

A thesis submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Electrical Engineering

By

Michael Trombley

B.S.E.E., Wright State University, 2015

2017

Wright State University

WRIGHT STATE UNIVERSITY

GRADUATE SCHOOL

December 14, 2017

I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY Michael Trombley ENTITLED Design of a Programmable Four-Preset Guitar Pedal BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF Master of Science in Electrical Engineering.

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Abstract

Trombley, Michael. MSEE, Department of Electrical Engineering, Wright State University, 2017. *Design of a Programmable Four-Preset Guitar Pedal*.

Many companies in the music industry offer programmable preset guitar pedals. Presets allow musicians to save time and focus on their act by recalling predetermined settings during a performance. A majority of the companies in the music industry offer up to hundreds of presets, but realistically the substantial amount of presets may have a negative effect on the musician's performance due to time constraints. The main contribution of this thesis is to address the musician by reducing the amount of presets offered in a guitar pedal design. Combining two systems, a digital control and audio processing circuit, will produce a programmable four-preset guitar pedal. Cost and size are design constraints that will also be taken into consideration. The techniques observed in this thesis will benefit the music industry because they can be adapted into other guitar pedal designs. This thesis closes with an evaluation of the final design, feedback from musicians in the community, and suggestions for future improvements.

Contents

1	Introduction	1
1.1	Guitar Pedals	1
1.2	Problem Statement	1
1.3	Motivation	2
1.4	Thesis Objectives	3
2	Guitar Pedal Design	4
2.1	Signal Management	4
2.2	Programmable Presets	9
2.3	Audio Circuit	14
2.4	Microcontroller	20
2.5	Power Circuit	25
2.6	Enclosure Layout	29
3	Results	32
3.1	PCB Design	32
3.2	PCB Assembly	34
3.3	Enclosure Assembly	37
3.4	Profit Margin	39
3.5	Musician Feedback	40
4	Conclusion	41
4.1	Summary	41
4.2	Contribution	41
4.3	Future Work	42
5	Bibliography	43

List of Figures

1.1	Red House Electronics' Eagle Feather guitar pedal	2
2.1	3PDT Switch	4
2.2	SPST Switch	5
2.3	True bypass switching system	6
2.4	Relay control circuit	6
2.5	Electromechanical relay	7
2.6	Transistor operating as closed switch	8
2.7	Transistor operating as open switch	8
2.8	Guitar pedal with three parameters	9
2.9	Preset routine	10
2.10	Traditional analog parameter design	11
2.11	Digital parameter design	12
2.12	LED network	13
2.13	Analog potentiometer connection	14
2.14	Digital potentiometer connection	15
2.15	Block diagram of the FV-1's architecture	16
2.16	Digital control from MCU to FV-1	17
2.17	24LC32A connection to FV-1	17
2.18	Input unity-gain buffer	18
2.19	Output unity-gain buffer	19
2.20	Application of the ATmega328P	21
2.21	AVR Dragon	23
2.22	Power circuit used in the guitar pedal design	26
2.23	Power circuit under correct polarity connection	27
2.24	Power circuit under incorrect polarity connection	28
2.25	Enclosure layout	30

3.1	EAGLE's schematic editor	33
3.2	EAGLE's board editor	33
3.3	EAGLE's custom library editor	34
3.4	PCB designed in EAGLE's board editor	35
3.5	PCB fully assembled	36
3.6	Enclosure fully assembled	37
3.7	LED Bezel	38
3.8	Light Tube	39

List of Tables

2.1	I/O pins used on the ATmega328P	24
3.1	Programmable four-preset guitar pedal profit margin calculations	40

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Finally, this thesis is dedicated to the memory of my father, who always told me to live for a purpose and to pursue my passion.

1 Introduction

1.1 Guitar Pedals

Guitar pedals can be seen all throughout the music industry. Confined in a small enclosure, guitar pedals are used in a live performance or a recording studio. By implementing a variety of audio processing techniques, guitar pedals modulate the instrument's signal to obtain a range of aural effects. The sound generated from guitar pedals offer a unique tool to the musician to assist in creating music. An example of a guitar pedal is as shown in Fig. 1.1.

1.2 Problem Statement

During a live performance, a musician may alternate between multiple parameter settings on a guitar pedal. The time required to modify the settings during a performance may interfere with the musician's ability to perform. Since musicians have to modify multiple parameter settings and time is limited, various companies in the music industry now offer guitar pedals with programmable presets. Programmable presets allow the musician to establish predetermined parameter settings, which then can be recalled during a performance. Recalling programmed presets will reduce the time to modify the settings and allows the musician to maintain focus on the performance. A majority of the companies in the music industry offer up to 200 presets, but none of these companies address the live musician directly. The ability to save up to 200 presets can seem advantageous but realistically, the substantial amount of presets may have an effect on the musician's performance. The time used to alternate from one preset to another in a system that offers up to 200 has the possibility of delaying the musician's performance. So although these companies tried to solve an issue, another problem was created.



Figure 1.1: Red House Electronics' Eagle Feather guitar pedal

1.3 Motivation

My solution is to design a programmable preset guitar pedal that is more relevant to live musicians than the current alternative offered in the music industry. By reducing the number of presets, musicians will be able to easily alternate between the presets in a timely manner on stage; allowing the musician to maintain focus on the performance. This thesis aims to combine two systems, a digital control and audio processing circuit, and together the two systems will produce a programmable preset guitar pedal. The digital control circuit will manage the user inputs and provide the necessary operations to create a programmable preset system. The audio processing circuit will modulate the instrument's signal to generate a reverb effect. Cost and size are design constraints that will also be taken into consideration. The techniques observed in this thesis will benefit the music industry because they can be applied to other guitar pedal designs; therefore, enabling programmable presets in a wide range of audio processing circuits.

1.4 Thesis Objectives

In chapter 2, each subsystem in guitar pedal design is analyzed and design requirements are distinguished. Chapter 3, using the requirements provided in chapter 2, the design's results will be observed and suggestions for future revisions of the guitar pedal will also be made. Chapter 4 closes with a summary of the thesis, contributions, and suggestions for future work.

2 Guitar Pedal Design

2.1 Signal Management

Traditional methods of audio signal switching in guitar pedals rely on using a foot switch. The foot switch has two positions: active and bypass. In the active position, the guitar's signal is directed into the effect pedal's circuit that will modify the signal. When the foot switch is in the bypass position, the effect pedal's circuit is bypassed and the signal is not modified. The music industry refers to this switching as true bypass switching because the effect pedal's circuit does not present a load to the input or output of the pedal [1].

A three-pole-double-throw (3PDT) foot switch is normally used in guitar pedals to provide true bypass switching and to notify the user when the foot switch is in the active or bypass position. The pole count represents the three separate circuits that the switch can control, while the throw count represents the two positions that the switch's poles can be connected to [2]. The 3PDT switch is as shown in Fig. 2.1. The 3PDT switch used in guitar pedals uses a



Figure 2.1: 3PDT Switch

latching method. The latching method locks the switch's poles into one of the two positions when pressed and therefore, requires a large amount of force to alternate between the switch's two positions. For musicians, the force required to alternate between the positions of the 3PDT switch can be strenuous when performing live. To reduce the amount of force required, the solution is to use a momentary switch. The momentary switch, unlike the latching switch, does not lock the switch's poles into one of the two positions and therefore, requires less force to be applied to the switch. The momentary switch selected is a single-pole-single-throw (SPST) normally open switch. The SPST switch is as shown in Fig. 2.2. The circuit in the momentary switch will be connected while



Figure 2.2: SPST Switch

force is being applied to the switch, otherwise the circuit will be disconnected [2]. Since the amount of poles will be reduced by using a momentary switch, a relay is used to perform the true bypass switching and the momentary switch will control the relay. In order to have the momentary switch control the relay, the configuration as shown in Fig. 2.3 must be applied. When the momentary switch is pressed, the input will be read from the microcontroller unit (MCU) and the relay control circuit will be toggled using output provided by the MCU.

The relay control circuit's purpose is to provide true bypass switching by

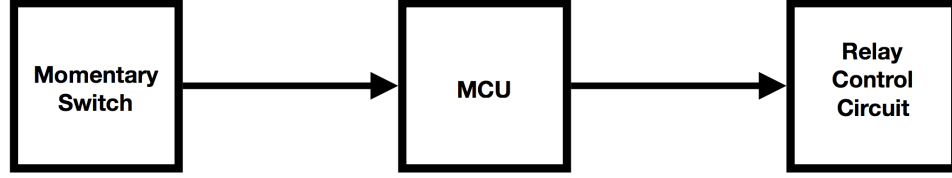


Figure 2.3: True bypass switching system

toggling between the active and bypass position using input obtained from the MCU. The relay control circuit is as shown in Fig. 2.4. The control circuit's

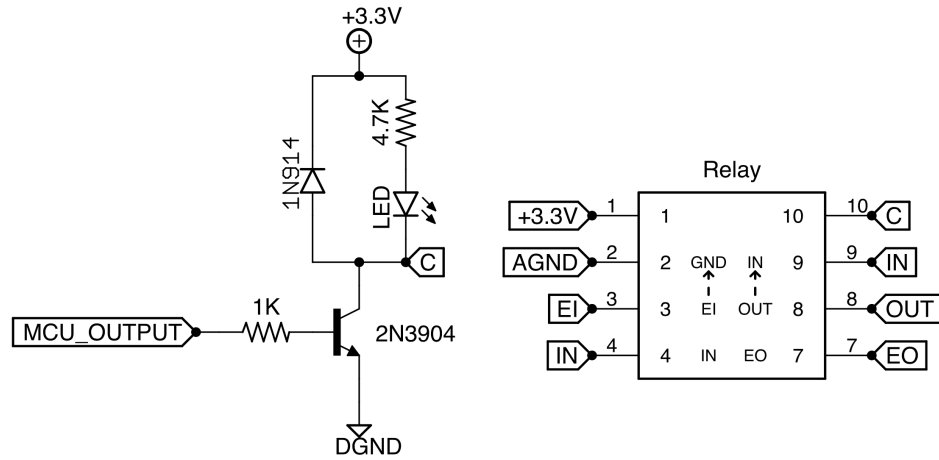


Figure 2.4: Relay control circuit

main components are the relay, flyback diode, light emitting diode (LED), and transistor.

The relay will be used to provide the true bypass switching and will reroute the guitar's signal relative to the pedal's current switch position: active or bypass. The relay is electromechanical and uses electricity to perform mechanical operations. An electromagnetic is located across the power terminals of the relay and when energized, a spring inside the relay is pulled to change the relay's switch position [3]. When current is applied to through the relay's power terminals, the pedal's switch position will be active. Otherwise, the pedal's switch position will be in bypass when there is no current applied though the relay's power terminals. An example of the electromechanical relay can be seen

in Fig. 2.5.

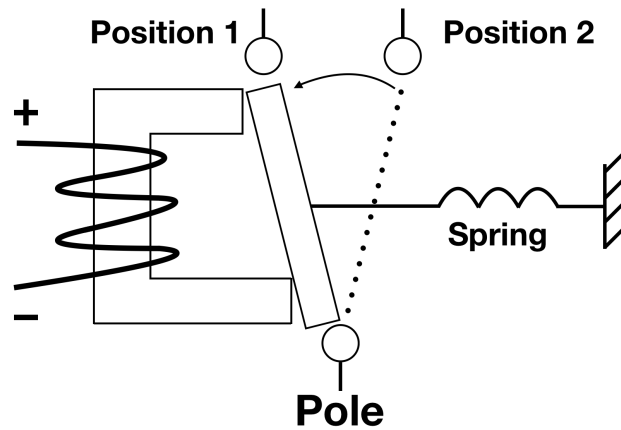


Figure 2.5: Electromechanical relay

The flyback diode is in parallel with the relay's power terminals to prevent damage to the control circuit. The electromagnetic across the power terminals of the relay contains a conductive coil wrapped around a magnet. When power to the relay is turned off, the magnetic field in the coil collapses. The collapsing magnetic field causes a reverse voltage spike across the power terminals that could damage the entire control circuit [3]. To reduce the voltage spike, the flyback diode is connected in parallel with the relay's power terminals. When the relay is turned off, the diode is forward biased and the voltage spike is reduced to a minimum. When the relay is turned on, the flyback diode will be reversed biased and only the relay will conduct current.

The LED will be used to notify the user that the pedal's switch position is active. A resistor is connected in series with the LED to limit current and to provide an acceptable brightness for the user. Both the LED and resistor are connected in parallel to the relay, this connection will allow the two components to be active simultaneously.

The transistor will operate as a switch to control the flow of current through the relay and LED. The transistor selected for the control circuit is a 2N3904 NPN bipolar junction transistor. To operate the transistor as a switch, the MCU's output will drive the transistor into saturation. For the NPN transistor

to enter saturation, the base-emitter voltage must have a minimum voltage of 0.65 V [4]. Once in saturation mode, the transistor will operate as a closed switch and begin to conduct current between the collector and emitter of the transistor as shown in Fig. 2.6 [5]. The current will flow through the relay and

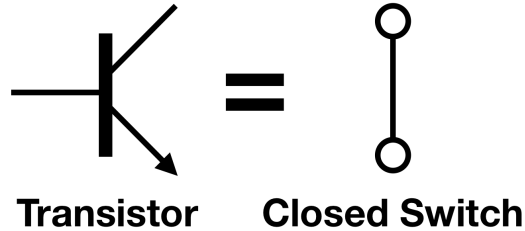


Figure 2.6: Transistor operating as closed switch

LED, allowing the control circuit to be in the active mode of the true bypass switching system. When the base-emitter voltage is below 0.65 V, the transistor will operate in the cut-off mode, no current will flow between the collector and emitter, and the transistor will operate as an open switch as shown in Fig. 2.7. When no current is flowing through the relay and LED, the circuit will be

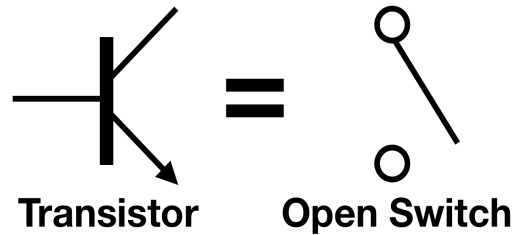


Figure 2.7: Transistor operating as open switch

operating in the bypass position of the true bypass switching system.

The MCU is used to obtain input from the momentary switch and toggle the control circuit between its active and bypass positions. When the momentary switch is pressed, the MCU outputs a digital high or low value. The value of the MCU's output will depend on the previous output condition before the switch was pressed. For example, if the output was high before the switch was pressed, the new output will be low. The digital high will output a dc voltage of 3.3 V, while the digital low connects the output pin to ground. The output

pin is connected to the transistor's base resistor. The base resistor will limit the amount of current to the transistor's base to reduce damage to the transistor [5]. When the MCU's output is high, the transistor is driven into saturation and the control circuit is in the active position. A low output from the MCU will result in the transistor operating in the cut-off region, where the control circuit will be in the bypass position.

2.2 Programmable Presets

Guitar pedals have multiple parameters that consist of filters, amplifiers, and time-varying effects. These parameters are used to modulate the instrument's signal. A three-parameter guitar pedal is shown in Fig. 2.8. Multiple sources

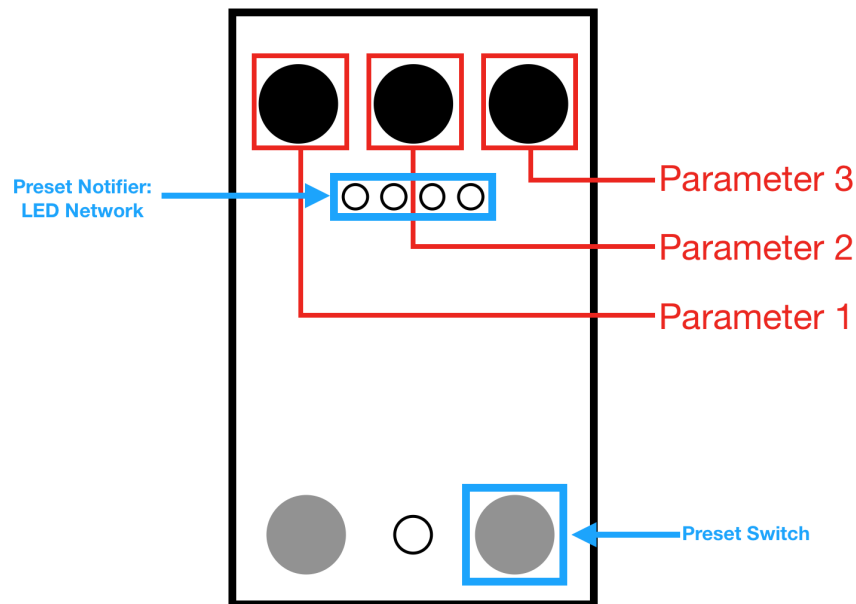


Figure 2.8: Guitar pedal with three parameters

of input are used to alter the parameters. A common form of user input includes: potentiometers and switches. In a tradition analog guitar pedal design, the potentiometers and switches are wired directly into the analog portion of the effect circuit. A guitar pedal that incorporates the tradition analog guitar design is limited because in-between songs, the parameters need to be manually

adjusted. If the musician is unable adjust the parameters before the next song, the performance could be disrupted. A solution is to implement preset parameters. The solution would allow the user to save pre-determined parameters that could be recalled during a performance. The user will benefit from recalling preset parameters during a performance because compared to the traditional analog design, the user will be able to adjust multiple parameters within a limited amount of time.

The preset parameters will be loaded and saved using a preset routine. The preset routine will allow the user to load and save parameters using a foot switch. The preset routine is shown in Fig. 2.9. The guitar pedal will save

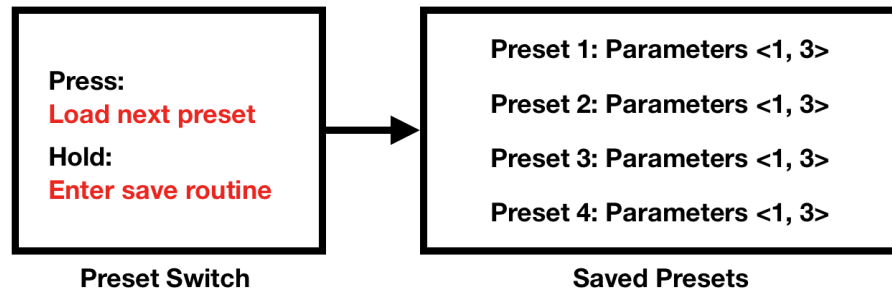


Figure 2.9: Preset routine

four presets and each preset will store three parameter settings. The presets will be saved and recalled using the preset switch. A network of four LEDs will be used to identify the current preset. To notify the user that one of the preset's parameters have been changed, the LED corresponding to preset will be dimmed. The preset switch and network of LEDs is shown in Fig. 2.8. The preset switch is a momentary foot switch that will read two different inputs: press and hold. When the preset switch has been pressed, the guitar pedal will perform the following: access the next preset, adjust the parameters accordingly, and toggle the LED network to turn only the corresponding preset LED on. When the preset switch has been held, the guitar pedal enters the save routine. The save routine will cause the current preset LED to blink, notifying the user that the guitar pedal is in the save routine. In the save routine, the

user will adjust the three parameters to their preferred value and select a preset to store the parameters. While in the save routine, the preset switch will read two different inputs: press and hold. When the preset switch has been pressed, the next preset LED in the network will blink. When the preset switch has been held, the parameter values will be stored in the current preset and the current preset LED in the network will stop blinking. If any of the potentiometers are moved while on a preset, the current preset LED brightness will be dimmed, notifying the user that a preset parameter has been modified.

The preset parameters circuit will incorporate a digital design into an analog concept. The traditional analog design is shown in Fig. 2.10. The analog po-

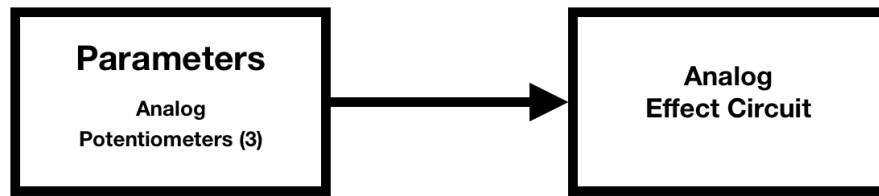


Figure 2.10: Traditional analog parameter design

tentiometers are wired directly into the effect circuit in the traditional design, which results in static values for each parameter. Implementing the digital parameter design shown in Fig. 2.11 will allow the guitar pedal to operate with preset parameters. The MCU reads the following inputs for the preset parameter design: a momentary switch and three analog potentiometers. The momentary switch is used to control the preset routine. The analog potentiometers send an analog voltage to the input of the MCU. The MCU sends output to the following: the preset notifier and three digital potentiometers. The output sent from the MCU to the preset notifier is dependent upon the current process in the preset routine. The three digital potentiometers are wired directly to the analog portion of the effect circuit and will replace the traditional analog potentiometers. The MCU converts the voltage from the analog potentiometers to a digital value that is sent to the digital potentiometers. The digital data will adjust each digital potentiometer to create a voltage that is equivalent to

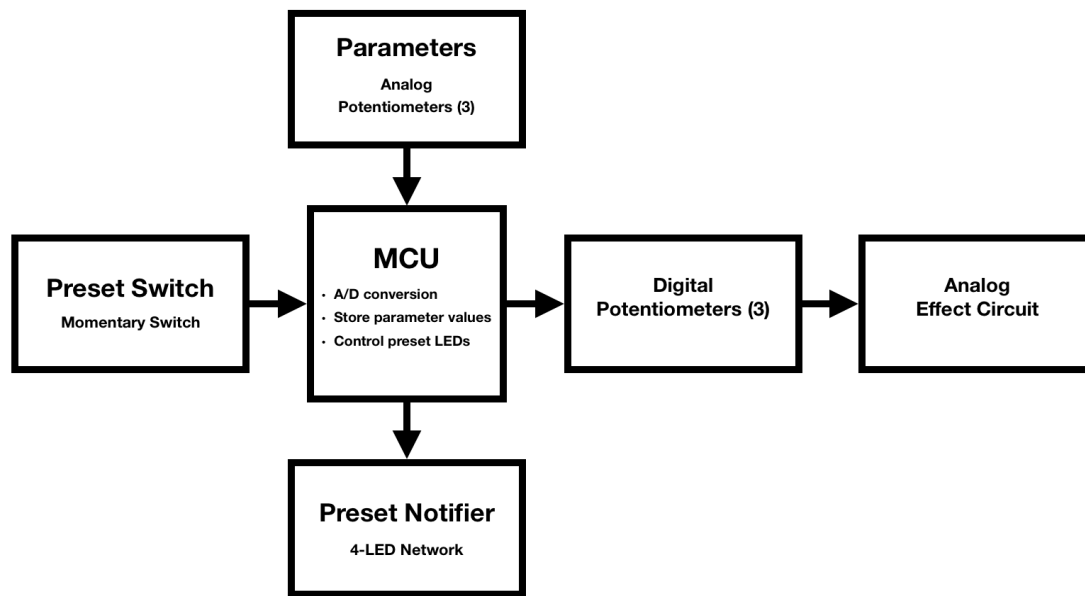


Figure 2.11: Digital parameter design

the analog voltage read from the analog potentiometers. The voltage from the digital potentiometer will then be applied to the analog portion of the effect circuit to control the effect circuit's three parameters. Converting the voltage from each analog potentiometer to a digital value allows the group of parameters to be saved as a preset in the MCU's memory, which cannot be done using the traditional analog design.

The LED network shown in Fig. 2.12 will be used for the preset notifier. The preset notifier will indicate one out of the four presets on the guitar pedal and notify user if a preset has been modified. The LED network's main components are the following: four transistors, four LEDs, and a resistor. The transistor selected for the LED network is a 2N3904 NPN bipolar junction transistor. The transistor, similar to the relay control circuit, will be operated as a switch. The MCU will be connected to each transistor's base and toggle each transistor switch. Only the transistor corresponding to the current preset will be operating in its saturation mode, while the other transistors will be in the cut-off region. For example, when the guitar pedal is currently on preset three, only third transistor will be in saturation mode and conducting current

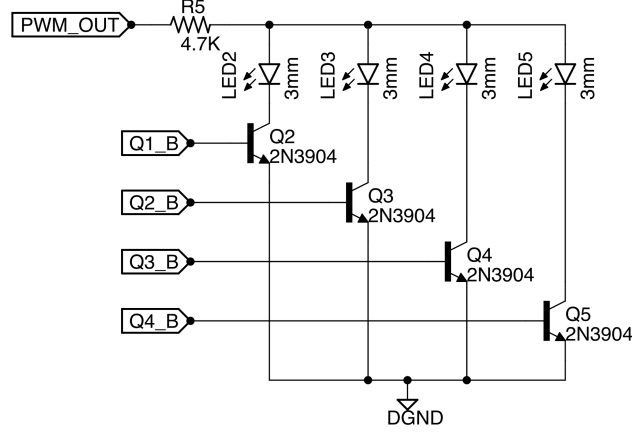


Figure 2.12: LED network

between the collector and emitter. A resistor is used to limit the current in each LED circuit and provide an acceptable LED brightness for the user. The connection, PWM_OUT, is a pulse-width-modulated (PWM) voltage provided from the MCU. The PWM output is chosen because the voltage supplied to the LED network will vary depending on the user's input. When the guitar pedal is on a preset and a potentiometer has moved, the PWM will supply a lower voltage to reduce the current LED's brightness and therefore, notifying the user that a change has been made the preset. The PWM will supply a voltage max voltage of 3.3 V when a preset is chosen, minimum voltage of 1 V when a preset has been modified, and 0 V when the user is not on a preset setting.

The analog potentiometer connection to the MCU is shown in Fig. 2.13. The potentiometers provide a continuous voltage ranging from 0 V to 3.3 V to the analog input of the MCU. The MCU uses the internal analog-to-digital converter to convert each analog voltage to a digital 8-bit value [6]. The digital 8-bit values then can sent via the serial peripheral interface (SPI) bus to the digital potentiometers as shown in Fig. 2.14. If the preset routine is in save mode, the 8-bit value can be saved as a preset in memory. The digital potentiometers operate analogous to the analog potentiometers. For example, if analog potentiometer one has a voltage of 2.8 V on its wiper, digital potentiometer one will

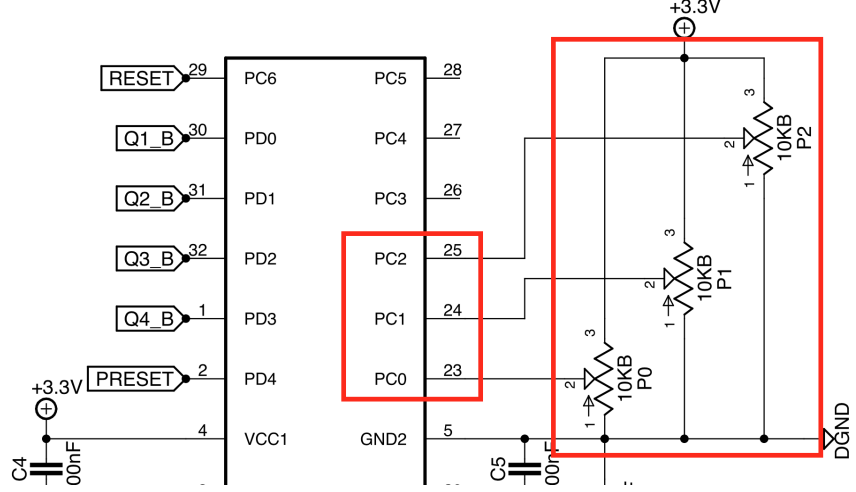


Figure 2.13: Analog potentiometer connection

also have a voltage of 2.8 V on its wiper. Since the analog and digital potentiometer values operate analogous to each other, the two are interchangeable. Therefore, the traditional analog guitar pedal design can be replaced by the digital alternative that will allow the user to save pre-determined parameters that can be recalled during a performance.

2.3 Audio Circuit

Natural reverb is created when a sound source is reflected in an environment and creates multiple reflections that build up and have their own delay. The reflections are heard even after the sound source has stopped because of the individual delays [7]. In a small room the delay is shorter and provides small reverberation, whereas in a larger room the delay will be longer, resulting in larger reverberation.

The reverb effect can be incorporated into guitar pedals to alter the natural reverb of the musician's instrument. In order to obtain the reverb effect, Spin Semiconductor's FV-1 digital signal processing (DSP) integrated circuit (IC) will be used. The FV-1 was created for standard audio applications in the music industry. A block diagram of the FV-1's architecture is as shown in Fig. 2.15. The FV-1 was chosen because of the following: integrated analog-to-digital

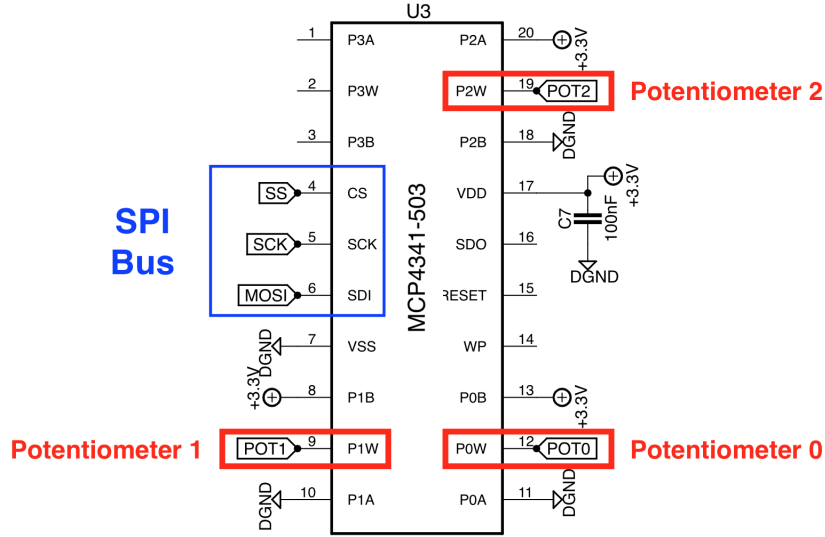


Figure 2.14: Digital potentiometer connection

converter (ADC) and digital-to-analog converter (DAC), external clock driver, potentiometer input, and external EEPROM interface.

Although the FV-1 is fully digital, the ADC and DAC are integrated so that the device can be treated as analog component [8]. Since the ADC and DAC are integrated on a single IC, this allows for reduced board space in the circuit design. Board space is crucial in guitar pedal circuit design because the musician has a limited performance space, which requires guitar pedals to be designed in smaller enclosures.

The FV-1 is designed to be ran using a standard 32768 Hz watch crystal oscillator or any other logic level clock source [8]. A 32768 Hz watch crystal oscillator will be used because of its size, cost, and effect on the FV-1's ADC and DAC sample rate. The watch crystal oscillator used in the design has a package size of 2 mm. The 2 mm sizing will reduce board space in the circuit design and allow the board design to be kept in a smaller enclosure. A watch crystal oscillator is common in electronics and therefore, inexpensive, reducing the cost of the build. The sample rate of the system will be applied depending on the oscillator's frequency [8]. At 32768 Hz, the ADC and DAC will have a bandwidth of 15 kHz, which will suffice for the audio range of the instrument's

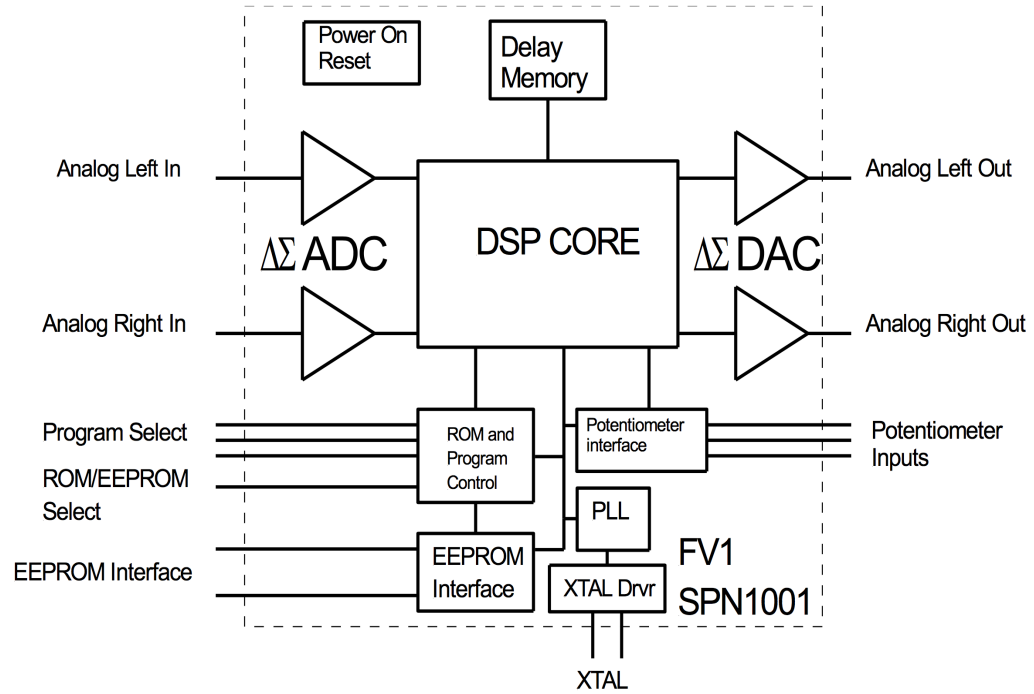


Figure 2.15: Block diagram of the FV-1's architecture

signal.

The FV-1 includes three potentiometer inputs that can be used to control parameters of the reverb. The three potentiometers will control the following parameters: mix, depth, and damping. The mix parameter will be used to control the amount of modulated signal sent to the output. When the mix potentiometer is fully counterclockwise, only the original signal is sent to the output. When the mix potentiometer is fully clockwise, only the modulated signal is sent to the output. The depth parameter will control the time delay of the reverb effect. When the depth potentiometer is fully counterclockwise, the delay will be short and result in small reverberation. When the depth potentiometer is fully clockwise, the delay will be long and result in large reverberation. The damping control will reduce high frequency content in the reflections. When the damping potentiometer is fully counterclockwise, high frequency content is reduced. When the reflection potentiometer is fully clockwise, high frequency content is not effected. Each potentiometer input of the

FV-1 will be connected to a digital potentiometer's wiper to allow digital control from the MCU. The digital control from the MCU to the FV-1 is as shown in Fig 2.14 and Fig 2.16.

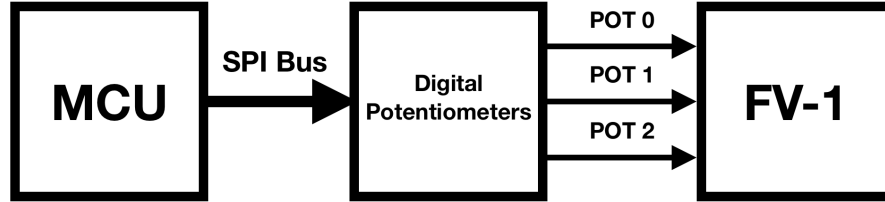


Figure 2.16: Digital control from MCU to FV-1

The FV-1 is also selected because the device allows for internal or external EEPROM program storage. The programs written and stored are algorithms used to manipulate the instrument's signal. The FV-1, when purchased, comes with eight programs that are stored in the internal EEPROM and these programs cannot be deleted or edited. The external EEPROM, however, will allow for storage of the desired reverb algorithm. The external EEPROM used is the 24LC32A from Microchip Technology Incorporated and the 24LC32A's connection to the FV-1 is shown in Fig. 2.17. The stored reverb algorithm will

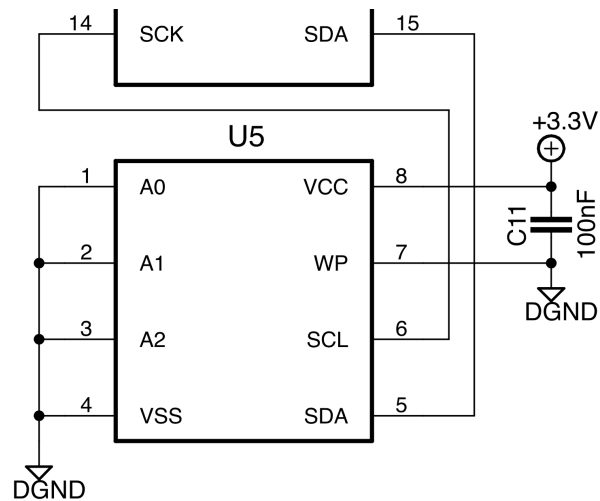


Figure 2.17: 24LC32A connection to FV-1

be transmitted from the 24LC32A to the FV-1 via the following four pins: SCL, SDA (24LC32A), SCK, and SDA (FV-1). The other pins not used on

the 24LC32A will be grounded. The reverb algorithm will be uploaded to the external EEPROM using the developmental board from Spin Semiconductor. Since the 24LC32A will be programmed on the developmental board and then connected to the FV-1, an 8-pin socket will be used in the circuit design to allow for simple installation and removal of the 24LC32A.

Since the FV-1 has built-in analog and digital converters, the digital component can be added to a circuit design similar to an analog component. The FV-1 requires that a low impedance be introduced at the input of the device and that a high impedance be introduced at the output of the device to ensure proper voltage transmission. The solution is to apply a unity-gain buffer at the input and output of the FV-1. The unity-gain buffer provides a high input impedance and a low output impedance, which is required for the FV-1 [9].

The unity-gain buffer that will be used for the guitar pedal design is as shown in Fig 2.18. The instrument's signal is sent from the relay to the input

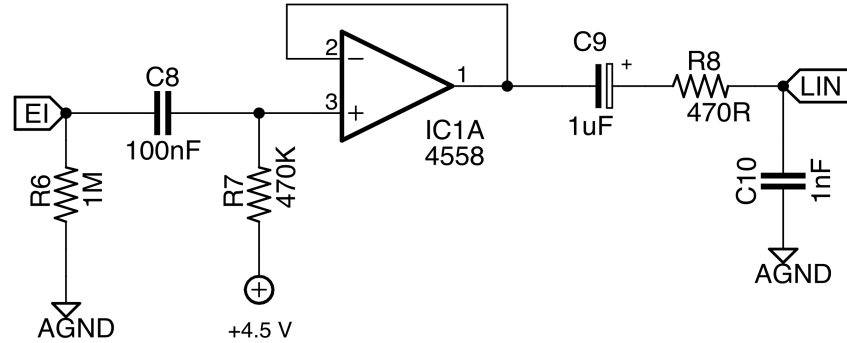


Figure 2.18: Input unity-gain buffer

buffer when the relay is in the active mode. The resistor R6 will be used to discharge the stored voltage in capacitor C8 while the relay is in the bypass mode. The dc coupling capacitor C8 will block the dc voltage from effecting other circuits connected to the input of the unity-gain buffer. The resistor R7 is used to bias the instrument's signal to virtual ground. The virtual ground has a voltage of 4.5 V and is set to half of the operational amplifier's operating voltage to ensure linear operation of the unity-gain buffer. The dc

coupling capacitor C9 will block the dc voltage from effecting the FV-1 that is connected to the output of the unity-gain buffer. The instrument's signal is then sent to a lowpass filter formed by R8 and C10. The lowpass filter is as recommended by Spin Semiconductor to remove the unwanted high frequency content from the signal [8]. After the low-pass filter, the signal is sent to the input of the FV-1.

After the reverb effect has been applied to the guitar signal, the signal is sent from the FV-1's output to the input of the output unity-gain buffer. The output unity-gain buffer is as show in Fig 2.19. The output unity-gain buffer

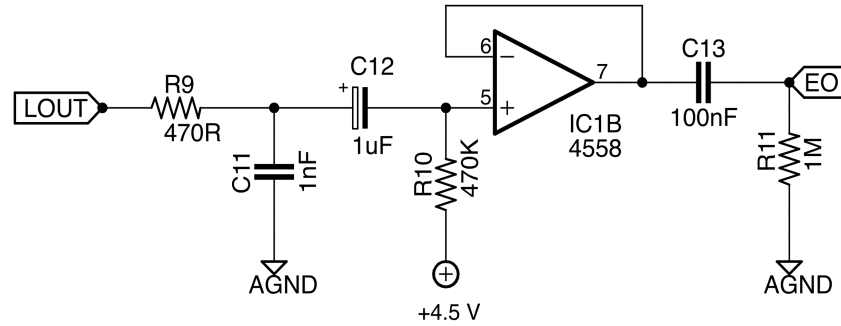


Figure 2.19: Output unity-gain buffer

ensures proper voltage transmission from the FV-1 to a circuit following the reverb guitar pedal. Similar to the input unity-gain buffer, the resistor R9 and C11 form a low-pass filter that is recommended by Spin Semiconductor and removes the unwanted high frequency content from the instrument's signal. The dc coupling capacitor C12 will block the dc voltage from effecting other circuits connected to the input of the unity-gain buffer. The resistor R10 is used to the bias the instrument signal to virtual ground. The dc coupling capacitor C13 will block the dc voltage from effecting other circuits connected to the output of the unity-gain buffer. The resistor R11 will be used to discharge the stored voltage in capacitor C13 while the relay is in the bypass mode.

2.4 Microcontroller

The microcontroller will be used to digitally control the guitar pedal based on the user's input. The requirements for the microcontroller are: operates on 3.3 V, SPI compatible, supports in-system programming, EEPROM for non-volatile storage, and has a minimum of 15 input/output (I/O) pins. The microcontroller that meets the requirements and that will be used for the design is Atmel Corporation's ATmega328P. The ATmega328P's application in the guitar pedal design is as shown in Fig. 2.20.

Spin Semiconductor's FV-1 requires that the IC be operated at a dc voltage of 3.3 V. To reduce the number of operating voltages used in the guitar pedal design, the solution is to use a microcontroller that will operate at the same voltage as the FV-1. The ATmega328P's operating voltage ranges from 2.7 V to 5.5 V. Since the ATmega328P has a variable operating range, the device can be operated at the same voltage as the FV-1 and therefore, will reduce the number of operating voltages used in the guitar pedal design.

SPI buses allow for high-speed synchronous data transfer between a microcontroller and the peripheral units that are connected to the device [6]. The ATmega328P supports SPI and the following pins make up the SPI bus: master input/slave output (MISO), master output/slave input (MOSI), SPI bus master slave select (SS) and SPI bus master source clock (SCK). The SPI pins are as shown in Fig. 2.20. The MISO bus line sends data from the peripheral device to the microcontroller. The MOSI bus line sends data from the microcontroller to the peripheral device. The SS bus line will send the connected peripheral device into its active mode, so the device will be able to receive data sent on the MOSI bus line. The SCK bus line ensures that the microcontroller and peripheral device are in sync when transmitting data. The SPI bus will be used to perform two operations in the guitar pedal design: sending data to the digital potentiometers and performing in-system programming.

The ATmega328P is a part of the 8-bit microcontroller family from Atmel

Corporation; therefore, the digital potentiometers connected to the SPI bus must be 8-bit SPI compatible. The digital potentiometer selected for interfacing with the ATmega328P is the MCP4341-503 from Microchip Technology Incorporated. The MCP4341-503 is a 7/8-bit SPI quad potentiometer IC and the device's application in the guitar pedal design is as shown in Fig. 2.14. The MCP4341-503 was selected because the device supports 8-bit SPI, operates at 3.3 V, and contains multiple digital potentiometers. Since the MCP4341-503 supports 8-bit SPI, the device can be easily integrated into the ATmega328P's SPI bus and the data transmission between the two devices will be supported by each other. The MCP4341-503's operation voltage has the same voltage as the FV-1 and ATmega328P, which will reduce the number of operating voltages used in the guitar pedal design. The MCP4341-503 contains four potentiometers that can be individually controlled by the SPI bus. Three of the four potentiometers will be used to control the three parameters on the FV-1. The integration of four potentiometers in one common package will also reduce the amount of space used in the circuit board design as opposed to using multiple data bus lines and digital potentiometers ICs to obtain the same result.

The ATmega328P supports in-system programming, which is a requirement for the guitar pedal design. In-system programming is a programming technique that enables the microcontroller to be programmed while installed in a complete system, rather than being programmed prior to installation. Multiple software revisions may occur during production and will require an update to the ATmega328P's firmware. The solution is to use in-system programming to update the firmware on the ATmega328P and therefore, the ATmega328P won't be replaced after each software modification. The firmware for the ATmega328P will be written in embedded C and uploaded to the microcontroller using Atmel Corporation's AVR Dragon. The AVR Dragon is as show in Fig. 2.21. The AVR Dragon by Atmel Corporation is low cost development tool designed for Atmel Corporation's microcontrollers. The AVR Dragon will be connected to a computer using a USB cable, then the firmware will be up-

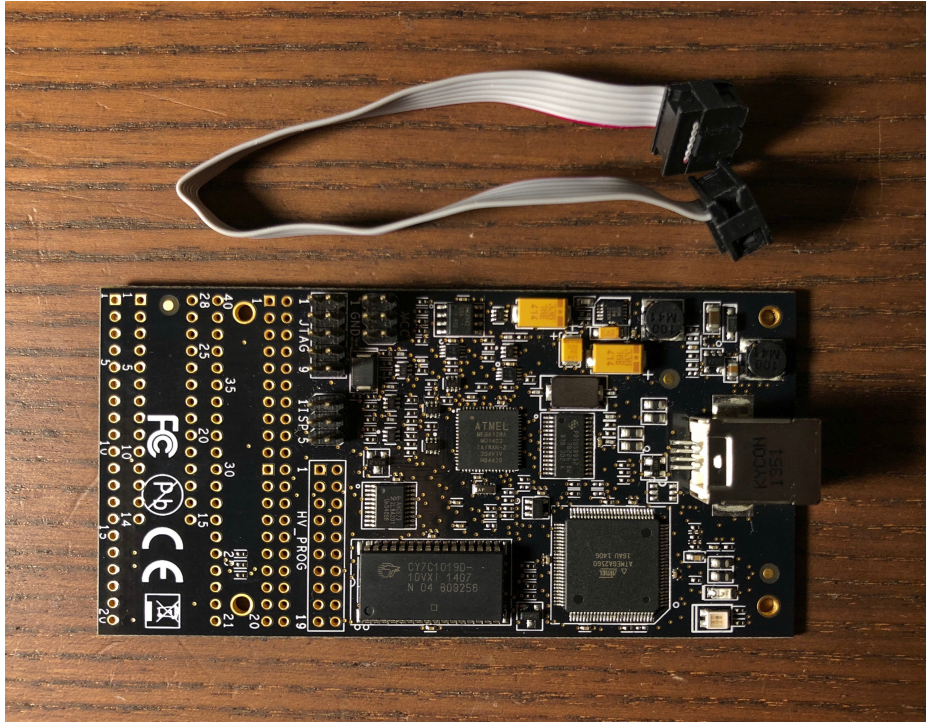


Figure 2.21: AVR Dragon

loaded to the ATmega328P's using a 6-pin connector cable that connects to the SPI bus. The ATmega328P's firmware will be uploaded on the SPI bus and will not require reprogramming until further updates have been made to the ATmega328P's firmware.

The guitar pedal design requires the preset parameters to be saved for later access. In order to save the preset parameters, a non-volatile memory storage is required to preserve the parameter data. The solution is to use the ATmega328P's internal EEPROM for non-volatile memory storage. Using the ATmega's internal EEPROM will not require the use of an external memory device and therefore, reduces the amount of circuit board space used in guitar pedal design. The preset parameter values will be written to the EEPROM when the software exits the save routine, while the EEPROM will be read when a preset is selected using the preset switch.

A microcontroller with a minimum of 15 I/O pins are needed for the guitar design and for this reason, the ATmega328P was chosen. The ATmega328P

has 32 pins that are used for power and I/O operations. The ATmega328P uses multiple input pins to obtain user input from different methods such as switches and potentiometers. After the input has been obtain and processed, multiple output pins are then used to send data and control other circuits in the guitar pedal. Table 2.1 shows a summary of the ATmega328P's I/O pins used in the guitar pedal design.

Analog In	Analog Out	Digital In	Digital Out	SPI Bus
Potentiometer 1	PWM_Out	RELAY_IN	Q1_B	SCK
Potentiometer 2	-	PRESET	Q2_B	MISO
Potentiometer 3	-		Q3_B	MOSI
-	-	-	Q4_B	SS
-	-	-	RELAY_OUT	

Table 2.1: I/O pins used on the ATmega328P

The analog input pins are going to be used to obtain a voltage input that will vary from 0 V to 3.3 V. Using three potentiometers, the wiper component of each potentiometer will be connected an analog input of the ATmega328P. The input voltage obtained from the analog inputs will be used to control the parameters of the FV-1.

The analog out pin is used to provide a PWM signal that will vary from 0 to 3.3 V. Initially, if the user is on a preset, the voltage on the pin will output 3.3 V. The output voltage will vary depending on the user's input during a condition. The voltage on the PWM pin will decrease from 3.3 V to 1 V, when the user has modified the current preset. If the user is not on a preset, the voltage on the PWM will be 0 V and no LED in the network will be turned on.

The digital inputs are going to be used to obtain an input of either 0 V or 3.3 V. The input RELAY_IN will be connected to a momentary foot switch that will cause the input pin to go from 3.3 V to 0 V if pressed. When the voltage on the input pin goes from 3.3 V to 0 V, the relay control circuit will toggle between a switching mode: bypass and active. The input PRESET will

be connected to a momentary foot switch that will cause the input pin to go from 3.3 V to 0 V if pressed. When the voltage on the input pin goes from 3.3 V to 0 V, the ATmega328P will begin to count the amount of time that the pin is held at 0 V. If the input pin is held at 0 V longer than 500 ms, the guitar pedal will enter the save routine. Otherwise, the guitar pedal will select the next preset.

The digital outputs will deliver an output voltage of either 0 V or 3.3 V. The output pins Q1_B, Q2_B, Q3_B, and Q4_B will be connected to separate transistors in the LED network. The output from the ATmega328P will drive each transistor into saturation and illuminate the LED connected to the transistor circuit. No more than one transistor will be driven into saturation at a time because each transistor will represent a preset on the guitar pedal. If no power is delivered to either one of the four transistors, then the user is in the live mode and no preset will be selected. The digital output for the four transistors is dependent upon the input received from the digital input PRESET. The digital output RELAY_OUT will drive the transistor in the relay control circuit. When the transistor is driven into saturation, the relay switching will be active. Otherwise, the relay switching will be in the bypass mode.

The pins SCK, MISO, MOSI, and SS will be used for programming and sending data the digital potentiometers. Initially, the AVR Dragon will upload the firmware onto the ATmega328P using the SPI bus. After the firmware has been uploaded and the pedal is operational, then the SPI will be used to communicate with the digital potentiometers.

2.5 Power Circuit

The guitar pedal's power section is designed to: supply the correct voltage to each device in the guitar pedal design, filter power, and provide reverse-polarity protection. The power section for the guitar pedal design is as shown in Fig. 2.22.

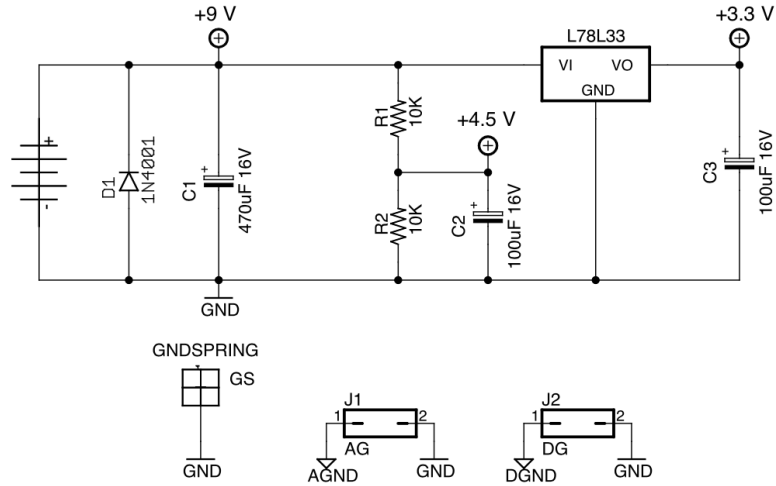


Figure 2.22: Power circuit used in the guitar pedal design

A majority of guitar pedals are designed to operate at the industry standard voltage of 9 V, so the the power circuit will be designed to operate at a voltage of 9 V and will have a max current rating of 100 mA. Using a power rating 9 V/100 mA will allow the guitar pedal to be accepted by most standard guitar pedal power supply units. The power circuit will also provide the following three voltages to different areas of the circuit: 9 V, 4.5 V, and 3.3 V. 9 V will be used to power the operational amplifiers. 4.5 V will provide a virtual ground to the inputs of the operation amplifiers. 3.3 V will provide power to following: 24LC32A, ATmega328P, FV-1, LED network circuit, MCP4341-503, and the relay circuit.

The capacitor C1 is connected to the 9 V power supply line to reduce any voltage ripple that may occur while the pedal is being supplied power. The 9 V is then reduced to 4.5 V using a voltage divider created by R1 and R2. The capacitor C2 will further reduce the voltage ripple that may occur on the 4.5 V supply line. Multiple devices in the design demand a 3.3 V power supply and the solution is to reduce the 9 V to 3.3 V by using a linear voltage regulator. The L78L33 3.3 V linear voltage regulator will be used to obtain an operating voltage of 3.3 V in the guitar pedal design. The L78L33 regulator is a low cost device and the device's power ratings are sufficient for the design. The

L78L33's low cost will reduce the overall production cost of the final product. The L78L33 provides a regulated output voltage of 3.3 V with a max current output of 100 mA [10]. The 3.3 V regulation meets the design requirements and will provide enough voltage to power the 3.3 V voltage line. The max rating for the guitar pedal is 100 mA, so the L78L33 100 mA current rating is within the limits of the design and therefore, meets the design's power requirements. The capacitor C3 will be used to reduce any voltage ripple that may occur on the output of the voltage regulator.

Reverse-polarity protection is provided to the circuit to prevent damage. If the power supply connected to the guitar pedal is reversed, the guitar pedal's circuit has the possibility of being damaged. In order to prevent damage to the circuit, diode D1 is used for reverse-polarity protection. When the guitar pedal is supplied with the correct polarity, the D1 is reversed biased. Reverse biasing D1 will cause the diode to act as an open circuit and the effect circuit will conduct current as normal. The power circuit under correct polarity operation is as shown in Fig. 2.23. The diode selected for the guitar pedal design is the

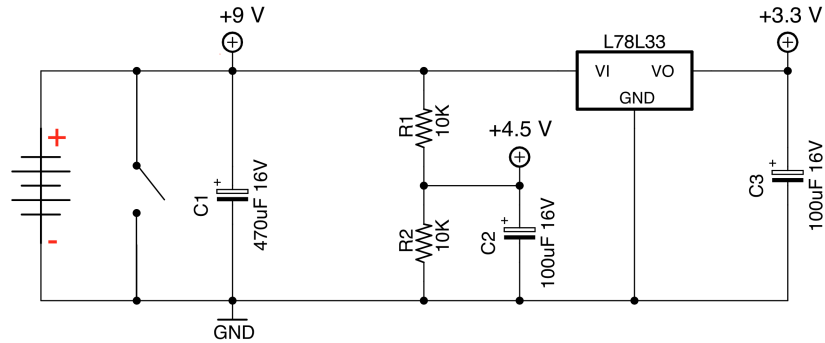


Figure 2.23: Power circuit under correct polarity connection

1N4001 general purpose rectifying diode. The 1N4001 was chosen because the diode's low cost will reduce the production cost of the guitar pedal and the diode's power ratings are in the range of the guitar pedal's operating power conditions. The 1N4001 has a dc blocking voltage up to 50 V when reversed biased and because the guitar pedal will be powered at 9 V, the 1N4001 will satisfy the design requirements [11].

When the guitar pedal is supplied with an incorrect polarity, both D1 and the effect circuit will conduct current. The forward voltage for the 1N4001 is 1 V [12] and because the diode is in parallel with the effect circuit, the supply voltage will be -1 V. The power circuit under incorrect polarity operation is as shown in Fig. 2.23. The forward-biased diode will reduce the reversed supply

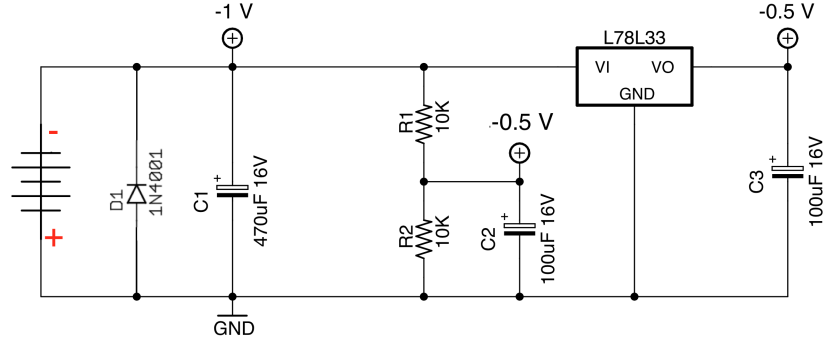


Figure 2.24: Power circuit under incorrect polarity connection

voltage from -9 V to -1 V and therefore, will reduce the probability of circuit failure.

The guitar pedal design includes both analog and digital components and therefore, requires caution when designing the PCB. The digital section in the design experiences fast and large current spikes, which are noisy and can create parasitics in the overall system. The analog section in the design is more susceptible to noise and so isolation from the digital section is necessary in order to avoid interference. Three grounding planes will be used to isolate the analog and digital systems from each other. The printed circuit board (PCB) design will consist of two copper layers and one layer will contain the grounding planes. The large copper planes have a low resistance and inductance. The copper planes act as a low-impedance return path for the signals, including the high-frequency currents caused by the digital system. The copper planes will also reduce the circuit's susceptibility to external electromagnetic interference (EMI) [13]. The analog and digital systems will each have a plane that connects to a star ground plane. The star ground plane will be connected to the power section and grounded to the guitar pedal's aluminum enclosure to further reduce

external EMI. The connection of the enclosure (GNDSPRING), star ground (GND), analog ground (AGND), and digital ground (DGND) is as shown in Fig. 2.22.

2.6 Enclosure Layout

A majority of guitar pedals in the music industry are featured on stage by musicians. The guitar pedals are usually installed on a pedalboard with other guitar pedals and therefore, require that the guitar pedal is able to fit within a confined space. One of the major design issues is to ensure that the enclosure will fit on a musician's pedalboard and that the circuit board will include all necessary parts of electronic design. The guitar pedal's enclosure layout requires space for the following: input and output jacks for the guitar signal, dc power connector, knobs for parameter control, LED bezels for both preset and active/bypass switching notifiers, and foot switches for relay and preset control. The guitar pedal's enclosure layout can be seen in Fig. 2.25.

A standard instrument cable has a 1/4-inch plug, so 1/4-inch jacks will be used for the guitar pedal's input and output connections. The dc power connector used will be a 2.1 millimeter negative-pin power connector, which is an industry standard for guitar pedals. Using an industry standard power connector will allow the pedal to be easily powered by a third-party power supply. Black aluminum knobs will be attached to the shaft of the potentiometer to provide the user with indication of the guitar pedal's parameter settings and to protect the potentiometer's shaft from damage. Each LED in the design will be covered using a bezel. The bezel will provide protection for the LED and will also diffuse the light that is emitted from the LED, allowing the LED notifiers to be seen at multiple angles during a live performance.

The enclosure used to contain the contents of the design will have a length of 119 millimeters and width of 66 millimeters. The length and width measurements are similar to other pedals in the music industry and therefore, will

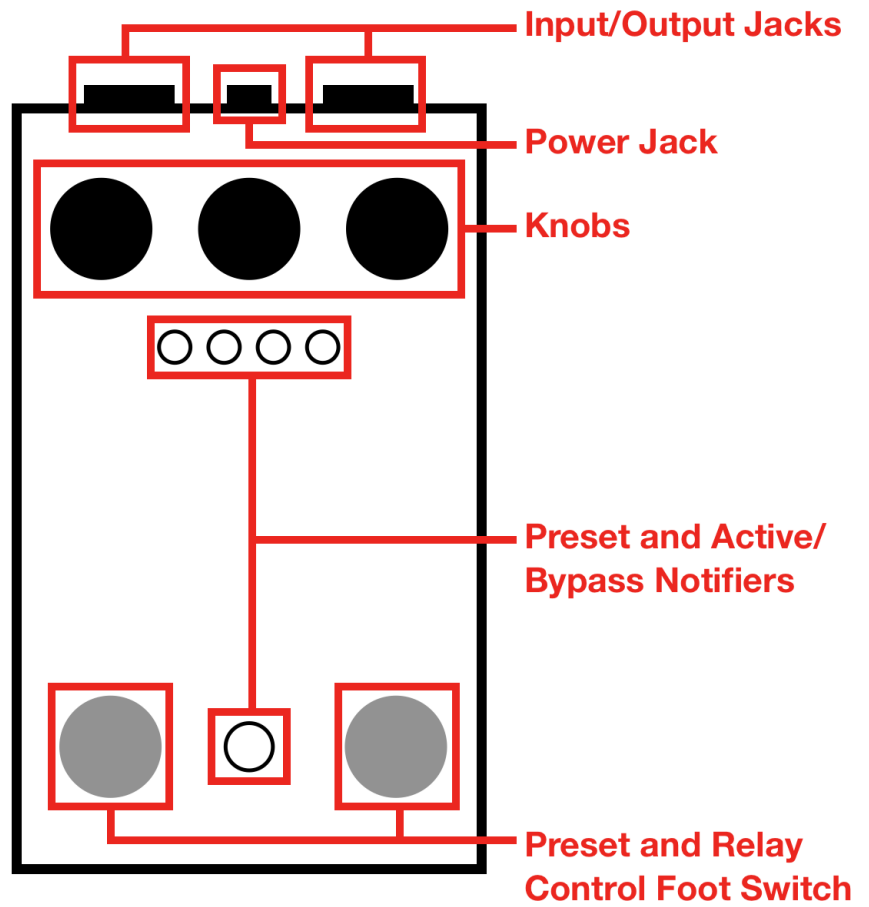


Figure 2.25: Enclosure layout

help accommodate the musician's pedalboard to save space. Since the guitar pedal will be controlled by a musician's foot and stepped on multiple times, an aluminum enclosure will be used ensure that the guitar pedal's contents are not damage during operation. The aluminum enclosure will also be connected to the circuit board's ground and will be used as a grounding shield to reduce the circuit board's susceptibility to effects caused by EMI. The foot switches used for relay and preset control will be located towards bottom of the enclosure, away from the knobs, this will ensure that the parameters will not be modified while the musician is stepping on either switch.

The circuit board design must meet the following requirements: cost efficient and fits into the selected enclosure. Cost is a main concern for the design and when researching multiple PCB manufacturer companies, the largest factor in cost was the size of the circuit board's area. The larger the circuit board, the more the PCB manufacturer charged. Many sites such as seedstudio.com offered a flat rate cost for boards that had a width and length under 100 millimeters by 100 millimeters, respectfully. Using the flat rate cost and size of enclosure, the circuit board will be designed to have a width of 60 millimeters and a length of 100 millimeters. The measurements for the circuit board are within the limits of enclosure and therefore, will satisfy the two requirements of cost efficiency and fitting the selected enclosure.

3 Results

3.1 PCB Design

The software used to design the PCB was EAGLE by Autodesk Incorporated. EAGLE was chosen because the design interface was schematic-to-board and included a custom library editor. EAGLE's schematic-to-board interface allowed the schematic to be drawn as shown in Fig. 3.1. Each component on the schematic was applied to the board editor as shown in Fig 3.2, where the components could then be placed and the connections routed. Using the custom library editor, each component in the design was created based on their package size and number of pins. Since the location of specific components like the 1/4-inch audio jacks and potentiometers were crucial, the custom library gave an accurate representation of each component and simplified the design process. An example of EAGLE's custom library editor is as shown in Fig. 3.3, where the 1/4-inch audio jack used in the guitar pedal design was created.

The analog, digital, and power sections of the circuit were subsystems taken into consideration when designing the PCB. Each subsystem was localized onto a section of the board to reduce the length of board traces and to allow the use of grounding planes for each subsystem. These techniques were mentioned in chapter 2 were determined to reduce the possibility of noise and other EMI issues associated with mixed-signal design. Also, the PCB design had to adhere to the proposed size requirements and the enclosure layout mentioned in chapter 2. The PCB for the guitar pedal in EAGLE's board editor is as shown in Fig. 3.4 and the PCB fully assembled is shown in Fig 3.5.

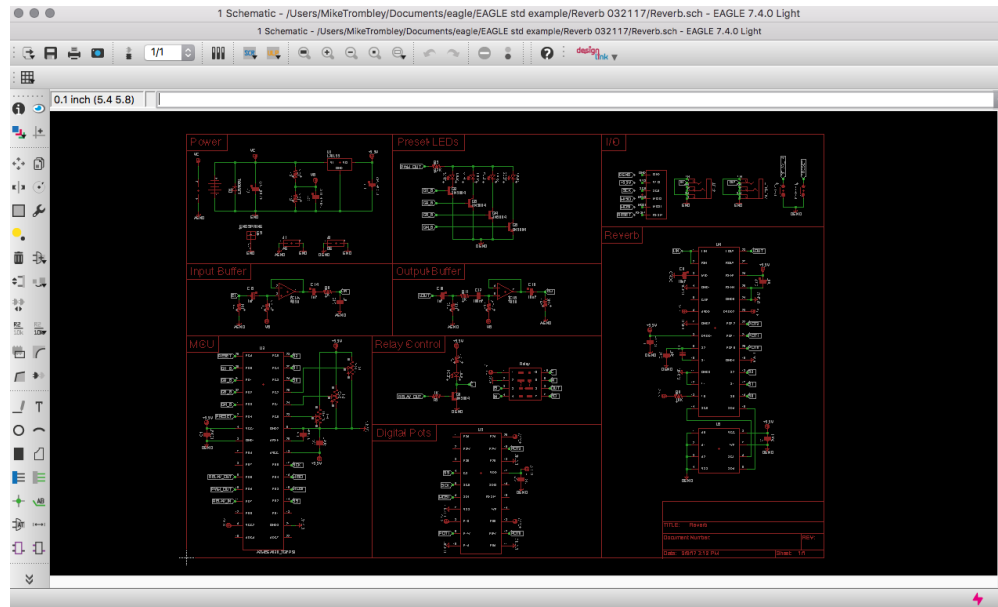


Figure 3.1: EAGLE's schematic editor

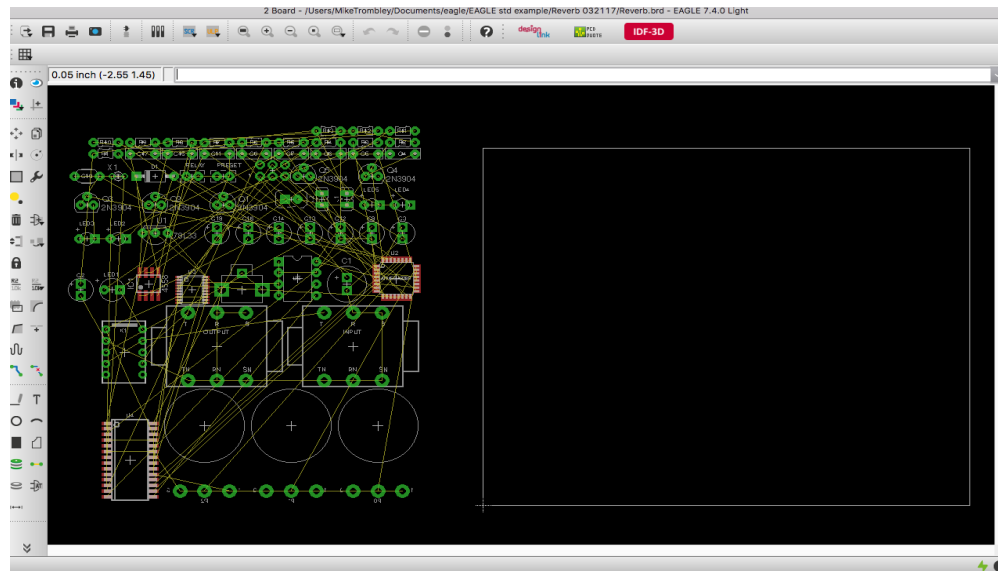


Figure 3.2: EAGLE's board editor

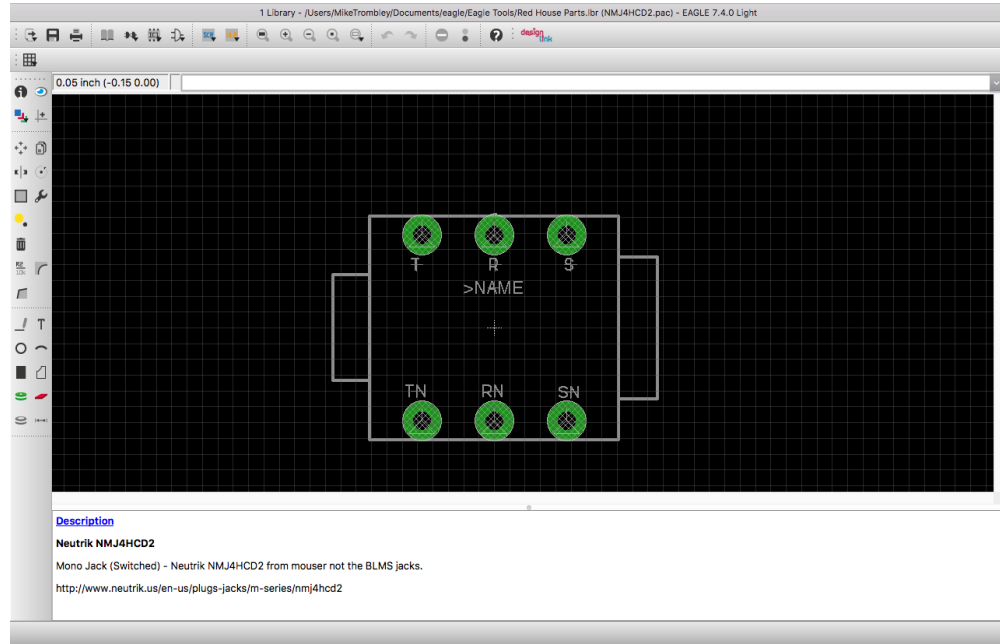


Figure 3.3: EAGLE's custom library editor

3.2 PCB Assembly

After being fully assembled and programmed, the next step was to test the operation of the guitar pedal and ensure that the circuit operated as expected. The guitar pedal was plugged into a 9 V dc power source, the input jack connected to a guitar, and the output jack connected to a guitar amplifier. The guitar's signal initially bypassed the effect circuit and when the relay switch was pressed, the LED came on and the instrument's signal was sent to the effect circuit. The preset switch alternated through the presets when pressed and entered the save mode when held. Based on their position, the three potentiometer inputs altered the reverb's parameters. All inputs and outputs of the circuit were verified and operated as expected.

After the guitar pedal was operated for a while, the circuit board's temperature would rise. The L78L33 used to regulate the supply voltage to the digital portion of circuit was the source of the heat. The current output of the regulator measured 160 mA, which was outside of regulator's 100 mA max operation [10]. The solution was to replace the overpowered L78L33 with an alterna-

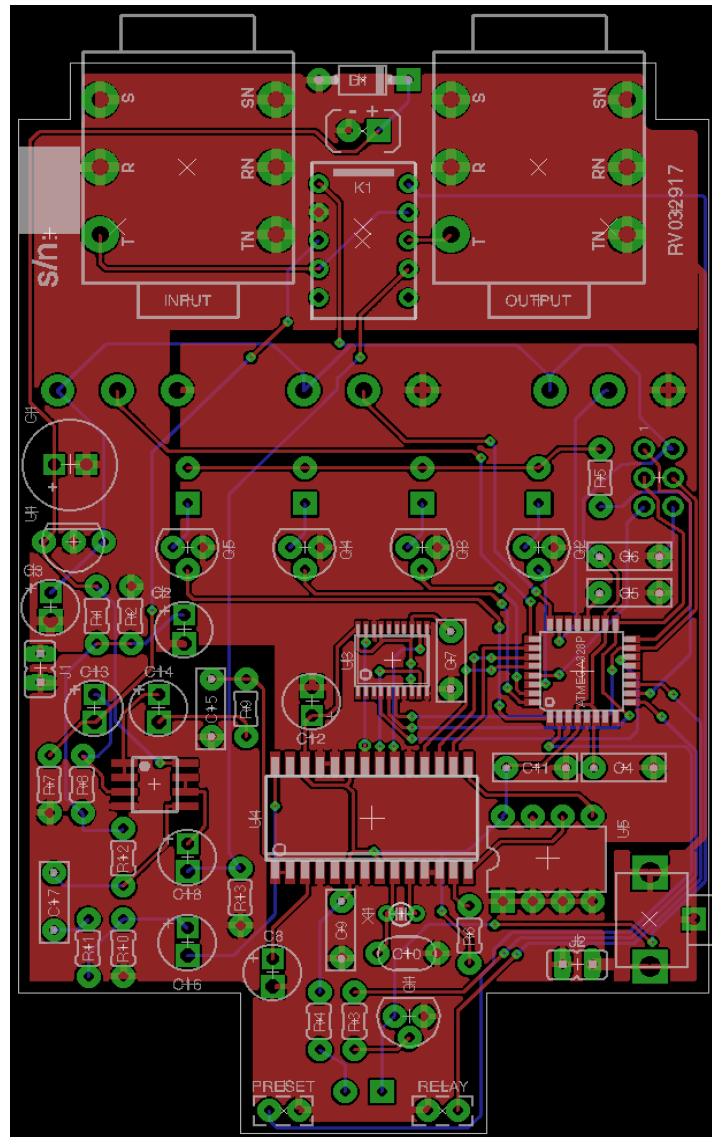


Figure 3.4: PCB designed in EAGLE's board editor

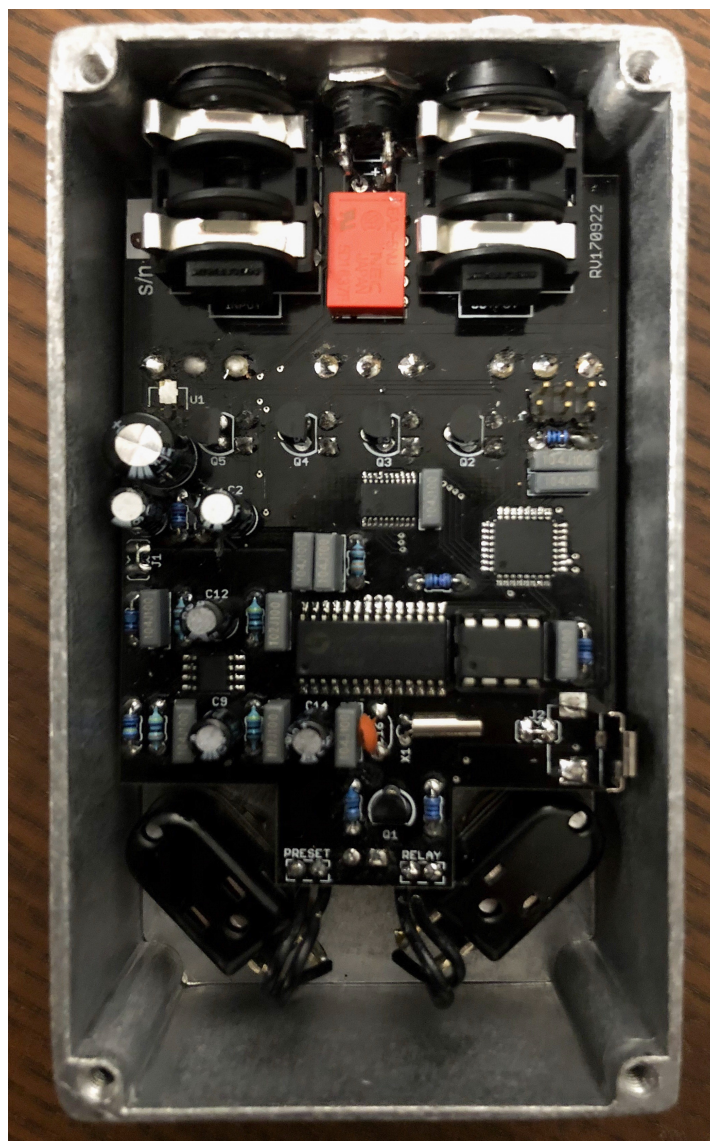


Figure 3.5: PCB fully assembled



Figure 3.6: Enclosure fully assembled

tive would be able to achieve a higher current output. A new regulator was sourced and the UA78M33CDCYR was found to be an adequate replacement. The UA78M33CDCYR offers 3.3 V voltage regulation with a max current output of 500 mA [13]. The UA78M33CDCYR was configured onto the guitar pedal's PCB and the board's temperature did not experience any increase in temperature; therefore, the board's temperature issue was fixed.

3.3 Enclosure Assembly

Using the design requirements provided in chapter 2, the enclosure was assembled accordingly and is as shown in Fig. 3.6.

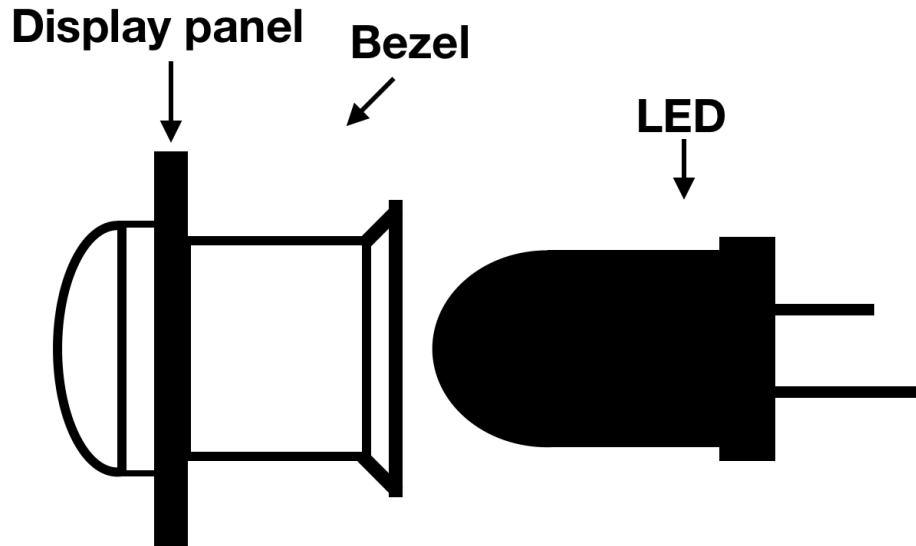


Figure 3.7: LED Bezel

The spacing of each knob, jack, LED, and switch was enough to not cause a user error. The knobs were far enough apart to ensure that when one knob was being modified, another was not moved. The jacks located at the top of the enclosure were separated adequately to ensure that the power and instrument cables could be inserted. The spacing of the foot switches was enough to allow the musician to successfully press each switch without making contact with the other switch.

Overall, the design experienced no major complications. A possible modification that could be done for the next revision would be to source a bezel alternative. Currently, the bezels require that the LED is inserted and locked into the bezel's socket. The bezel's socket can be seen in Fig. 3.7. However, during assembly, the LEDs were difficult to insert into the bezel's socket. Having to ensure that the LEDs were correctly lined and inserted with their respective bezels, turned out to be an meticulous task and process consumed most of the assembly time. A possible alternative for the LED bezels would be to use light tubes. An example of a light tube is as shown in Fig 3.8. The light tubes would significantly reduce the assembly time because each LED wouldn't require any insertion. The light tubes would be placed through the enclosure's

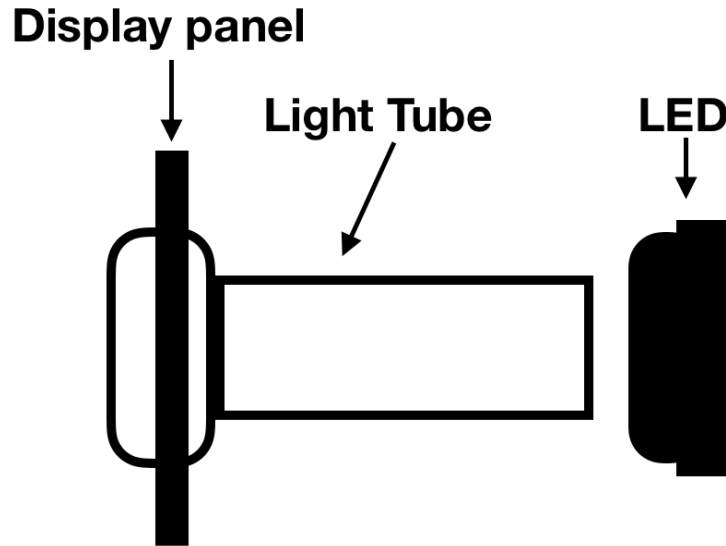


Figure 3.8: Light Tube

holes and the circuit board would be inserted into the enclosure without any LED adjustment.

3.4 Profit Margin

Profit margin is an analytical tool used in business to determine the percentage of revenue after the product's cost has been examined. If cost exceeds or is near revenue, then the profit margin will be low and the product will have a low return. The profit margin will help put the cost into perspective and determine if the product is worth selling in a market. The average price of a reverb guitar pedal that offers programmable presets is approximately \$300. A majority of these guitar pedals offer multiple types of reverb and extra parameter controls. Since programmable four-preset guitar pedal has one type of reverb and three parameters the sales price will be set at \$225.00. The cost of goods and labor for the guitar pedal was approximately \$62.00. Using the sales price and cost, the profit margin for the programmable four-preset guitar pedal was calculated at 72.5%. A review of the calculations can be seen in table 3.1.

Cost and labor	\$62.00
Sales Price	\$225.00
Profit Margin	72.5%

Table 3.1: Programmable four-preset guitar pedal profit margin calculations

A profit margin of 72.5% shows that there will be a profit when selling the guitar pedal in a market and that the cost is within a reasonable range. The calculations do not consider the discounted pricing that a dealer would receive, so when selling to a merchant one should expect the profit margin to vary slightly based on discounted pricing.

3.5 Musician Feedback

The programmable four-preset guitar pedal was displayed at three guitar shows and musicians were given the opportunity to play the device. “Larger companies do offer a range of guitar pedals but many do not address us [musicians]” and “simplicity and practicality go far” were opinions voiced by a majority of the musicians who played the guitar pedal at the shows. The musicians were happy that their needs were being address directly, which was an objective of the guitar pedal’s design. The musicians were also satisfied with the practicality of the guitar pedal’s programmable preset interface; furthermore, verifying that the design’s objective were being met.

4 Conclusion

4.1 Summary

In chapter 1, the significance of the guitar pedal and programmable presets was introduced. The problems facing current programmable preset guitar pedals was addressed along with a solution to reduce the number of presets offered in a guitar pedal, which would improve the musicians performance. The solution would require a digital control and audio processing circuit to be able to produce a programmable preset guitar pedal. In chapter 2, each subsystem in guitar pedal design was analyzed. Chapter 3, the design results were observed. Using the constraints provided in chapter 2, the PCB was designed and assembled in the enclosure. Suggestions for future revisions of the guitar pedal were made. Since cost was a design constraint, the guitar pedal's profit margin was explained to show the benefits of the design. Feedback from musicians in the community was also mentioned and used to verify the advantages of the programmable four-preset guitar pedal design.

4.2 Contribution

With the advancement in technology and an increase in the guitar pedal market, programmable preset guitar pedals are becoming more in demand by musicians. The demand is now forcing companies in the music industry to consider programmable presets in their designs. The techniques observed in this thesis will benefit the music industry because designs that currently don't incorporate programmable presets could be modified to include presets. By integrating the digital control circuit designed in this thesis to the analog portion of an audio processing circuit, a guitar pedal would now have preset capability.

4.3 Future Work

Future work that could be done on the programmable four-preset guitar pedal is to incorporate Music Instrument Digital Interface (MIDI) communication. MIDI is a communication standard that was created in the music industry to allow music electronics to accept instructions and to perform specific actions based on the instructions [13]. The ATmega328P used in the programmable four-preset guitar pedal design has the capability of processing MIDI commands, but the hardware for MIDI would have to be added to the digital circuit. The MIDI commands then could be used to control the relay switching and recall/save presets, and modify the parameters of the audio processing circuit.

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